practice, this is accomplished by attaching the grating to an actuator such as a piezoelectric element, then stretching the fiber some determinable amount. If the positional relationship between the actuator and the fiber is maintained, then one can theoretically deduce the Bragg grating wavelength by measuring the displacement of the actuator.

But it is known that if there is some lost motion between the fiber and the actuator, then a measurement of the actuator displacement will result in an erroneous wavelength determination. For example, when strain tuning a coated optical fiber, this effect is almost unavoidable, as the known attachment techniques will involve some sort of epoxy with a limited holding ability. Additionally, tuning the fiber Bragg grating by applying tensile strain is considered to be an unacceptable method from the perspective of fiber reliability, since the lifetime of a fiber can be significantly reduced by continuously stressing it.

Alternatively, another known method encases the Bragg gratings in an all glass element capable of sustaining high compressional loads, which has the potential to be incorporated into a device which can be used to reliably and accurately tune a Bragg grating by strain. The technique was originally applied to pressure transducers and

the glass element is measured, then there will be an error introduced into the measurement.

SUMMARY OF INVENTION

The present invention provides a tunable optical device having a compression tuned optical structure and a displacement sensor.

The compression tuned optical structure responds to an optical signal, and further responds to a displacement sensor signal, for providing a compression tuned optical structure signal containing information about a change in an optical characteristic of the compression tuned optical structure, and for also further providing an excitation caused by a change in a displacement of the compression tuned optical structure.

The displacement sensor responds to the excitation, for providing the displacement sensor signal containing information about the change in the displacement of the compression tuned optical structure.

The compression tuned optical structure may be in the form of a dogbone structure that is an all-glass compression unit having wider end portions separated by a narrower intermediate portion having a Bragg grating therein.

affixed to or formed on a respective one of the wider end portions. The narrower intermediate portion may have a Bragg grating or a Fabry-Perot interferometer arranged therein. The Fabry-Perot interferometer may include a pair of fiber Bragg gratings separated by a predetermined distance.

The displacement sensor may also include inductive sensing using two coils affixed to the compression tuned optical structure for measuring a change in inductance between the two coils. Other gap sensing techniques may be used, such an optical, magnetic, microwave, time-of-flight based gap sensors. Moreover, a force applied on or about the compressive element (i.e. grating or Fabry-Perot interferometer gap) may be sensed, and fed back to control the compression tuning of the optical structure.

In effect, this present invention provides a device, which combines a highly accurate means of measuring displacement with a compression tuned optical structure, including a tunable element having a fiber Bragg grating or Fabry-Perot interferometer. This hybrid device will enable a true indirect means of controlling the wavelength of the fiber Bragg grating or Fabry-Perot interferometer without the need for optical closed loop control. The device combines a highly accurate, and potentially drift-free,

capacitance (as opposed to a plate separation which demonstrates an inversely proportional dependence).

In addition to the potential uses of the hybrid capacitive or inductive sensor and tunable FBG, other devices formed in the compression element would also benefit from the addition of a capacitive displacement sensor. Such examples of these might be a fiber Fabry-Perot pair, Bragg grating pairs, a distributed feedback laser, an interactive Bragg grating laser.

The whole thrust of the present invention is to avoid using optical light transmitted from the compression tuned optical structures to tune the wavelength of the compression element, which increases the light available to the overall system. For example, if n compression tuned optical structures are connected in series, and a respective x% of light is used for each of the n compression tuned optical structures, then approximately nx% of light may be used to tune the overall system, which may significantly reduce the amount of light available to the overall system. In effect, the present invention provides an open-loop control system in relation to optical performance for tuning the compression element.

The foregoing and other objects, features and advantages of the present invention will become more

The structure of the compression-tuned dogbone structure 104 is also shown and described in more detail in patent application serial no. 09/456,112 (CiDRA File No. CC 0129), discussed above.

Figure 3: Tube-in-tube Capacitance Sensor Arrangement

Figure 3 shows a tube-in-tube capacitance sensor arrangement generally indicated as 100 that may be used in the tunable optical device shown in Figure 2. The tube-in-tube capacitance sensor arrangement 100 is shown in relation to an optical fiber 102 coupled to a compression tuned glass element 104. The tunable optical device 100 has a "tube-in-tube" design which can be used to measure a displacement of the compression tuned glass element 104 using a capacitive sensor where the effective area changes with displacement.

As shown, the compression tuned glass element 104 has the "dogbone" structure having two wider end portions 104a, 104b separated a narrower intermediate portion 104c. One wider end portion 104a has an inner tube 106 having an inner capacitive plate 108, while another wider end portion 104b has an outer tube 110 having an outer capacitive plate 112. The narrower intermediate portion 104c has a compression element 114 in the form of a fiber Bragg grating. The compression element 114 may also be in the form of a Fabry-

in the art would be able to implement without undue experimentation the electronics circuit (not shown) to measure the change in capacitance between the two capacitive plates 108, 112.

Figure 4: Single Tube Capacitance Sensor Arrangement

Figure 4 shows a single tube capacitance sensor arrangement generally indicated as 200 that may be used in the tunable optical device 100 shown in Figure 2. The single tube-in-tube capacitance sensor arrangement 200 is shown in relation to an optical fiber 202 coupled to a compression tuned glass element 204. Similar elements in Figures 2-4 are labelled with similar reference numerals with the addition of 100.

The design in Figure 3 above is simplified as shown in Figure 4 by elimination of the one tube 110 and extending the remaining tube 206 over the larger diameter of the compression tuned glass element 204.

As shown, the compression tuned glass element 204 has two wider end portion 204a, 204b separated by a narrower intermediate portion 204c. One wider end portion 204a has an inner tube 206 having an inner capacitive plate 208, while another wider end portion 204b has an outer surface with an outer capacitive plate 212.

The single tube capacitance sensor arrangement 200 greatly eases manufacturing and can eliminate alignment issues with other designs. One complication with the delta area based capacitive sensor could be the limited area change of the sensor and, therefore, a restriction of the resolution of the measurement.

Figure 5: Multiple Tube-in-Tube
Capacitance Sensor Arrangement

Figure 5 shows a multiple tube-in-tube capacitance sensor arrangement generally indicated as 300 that may be used in the tunable optical device 100 shown in Figure 2. The multiple tube-in-tube capacitance sensor arrangement 300 is shown in relation to an optical fiber 302 coupled to a compression tuned glass element 304. Similar elements in Figures 3-5 are labelled with similar reference numerals with the addition of 100. The tunable optical device 300 has multiple tubes that could be interleaved to increase the effective area change as the compression element is compressed.

As shown, the compression tuned glass element 304 has two wider end portions 304a, 304b separated a narrower intermediate portion 304c. One wider end portion 304a has tubes 306a, 306b having capacitive plates 308a, 308b, 308c,

while another wider end portion 104b has tubes 310a, 310b with capacitive plates 312a, 312b, 312c.

Figure 6: Tube-in-Tube Capacitance Differential Sensor Arrangement

Figure 6 shows a tube-in-tube capacitance differential sensor arrangement generally indicated as 400 that may be used in the tunable optical device 100 shown in Figure 2. The tube-in-tube capacitance differential sensor arrangement 400 is shown in relation to an optical fiber 402 coupled to a compression tuned glass element 404. Similar elements in Figures 3-6 are labelled with similar reference numerals with the addition of 100.

The tube-in-tube capacitance differential sensor arrangement 400 is formed as a differential sensor, so one capacitive section would decrease in value while another capacitive section increases providing a differential measurement which can provide increased resolution.

As shown, the compression tuned glass element 404 has two wider end portions 404a, 404b separated a narrower intermediate portion 404c. One wider end portion 404a has an inner tube 406 having capacitive plates 408a, 408b, while another wider end portion 404b has an outer tube 410 with

capacitive plates 412a, 412b. In operation, one capacitance value will decrease with compression, while the other capacitance value will increase with pressure. For example, as shown, if a compression force is applied, then the capacitance between plates 408a, 412a decreases (less overlapping plate area), while the capacitance between plates 408b, 412b increases (more overlapping plate area), and vice versa, when the compression force is relaxed.

A person skilled in the art would be able to implement without undue experimentation a differential electronics circuit (not shown) to measure the change in capacitance between the capacitive plates 408a, 412a, or 408b, 412b.

Figure 7

Figure 7 shows a part of a tunable optical device generally indicated 500 having a capacitance sensor arrangement with capacitive elements 502, 504, which may be plates or rods, as shown. Similar elements in Figures 2 and 7 are labelled with similar reference numerals.

The displacement sensor 24 (Figure 1) or the displacement circuit 70 (Figure 2) is not shown but would be connected to the capacitive elements 502, 504.